Electronically Tunable Current/Voltage- mode Universal Biquad Filter using CCCCTA

S. V. Singh[1], S. Maheshwari[2], and D. S. Chauhan[3]
[1]Department of Electronics and Communications, Jaypee University of Information Technology, Waknaghat, Solan-173215 (India)
Email: sajaivir@rediffmail.com
[2]Department of Electronics Engineering, Z. H. College of Engineering and Technology, Aligarh Muslim University, Aligarh-202002 (India)
Email:sudhanshu_maheshwari@rediffmail.com
[3]Department of Electrical Engineering, Institute of Technology, Banaras Hindu University, Varanasi-221005 (India)
Email:pdschauhan@gmail.com

***Abstract*— This paper presents an electronically tunable current/voltage mode universal biquad filter using current controlled current conveyor transconductance amplifiers (CCCCTAs). The proposed filter employs only two CCCCTAs and two grounded capacitors. The proposed filter can simultaneously realize low pass (LP), band pass (BP) and high pass (HP) responses. Realization of band reject (BR) and all pass (AP) responses are also feasible. The circuit can also be operated in mixed mode with either voltage or current input and current or/and voltage outputs, thus the configuration is versatile. The circuit enjoys an independent current control of pole frequency and bandwidth. Moreover, the LP and BP gain can be independently tuned by external biasing current of active elements without disturbing the pole frequency, quality factor and bandwidth. Both the active and passive sensitivities are no more than unity. The validity of proposed filter is verified through PSPICE simulations. The total power consumption is about 0.641mW at ±1.85V supply voltages.**

***Index Terms*— CCCCTA, tunable filters, biquad, universal**

I. Introduction

In analog signal processing, continuous time (CT) filters play an important role for realizing frequency selective circuits. In analog circuit design, current mode approach has gained considerable attention. This stems from its inherent advantages such as wider bandwidth, larger dynamic range, less power consumption, simple circuitry [1]. Second generation current conveyors (CCIIs) have been found very useful in filtering applications. The applications and advantages in the realization of various active filter transfer function using current conveyors have received considerable attention [2-7]. However, CCII-based filters do not offer electronic adjustment properties. The second generation current controlled conveyor (CCCII) introduced by Fabre at [8] can be extended to the electronically adjustable domain for different applications. In recent past, there has been greater emphasis on design of current mode current controlled universal active filters[9-20] using CCCIIs. The circuit reported in [9-11] uses three CCCIIs and two grounded capacitors whereas [12] uses two CCCIIs and two capacitors but one of the capacitor is floating which is the disadvantage from the IC fabrication point of view. The circuits proposed in refs. [13-16] enjoy high impedance outputs but uses excessive number of component counts. Moreover, all these circuits [13-16] can realize LP, HP, BP, BR and AP responses by connecting appropriate output currents without any passive component matching conditions. The circuit [15] can also be used as mixed mode operation. The circuit in [17] has orthogonal tuning capability of the characteristic parameters ω_o and Q, grounded capacitors and high impedance outputs. However, it uses too many active components (five CCCIIs) and passive components (three capacitors). The circuit reported in [18-19] uses three CCCIIs and two grounded capacitors where as [20] uses four CCCIIs and two grounded capacitors and enjoy high impedance outputs but uses ±types of CCCIIs which increases the hardware of the circuit. The circuit in [21] involves three CCCIIs and two capacitors, and it can provide high impedance outputs. However, the characteristic parameters (ω_o and Q) can not be orthogonally adjusted.

Recently, a new current mode active building block, which is called as a current controlled current conveyor transconductance amplifier (CCCCTA), has been proposed [22] which is the modified version of CCTA. This device can be operated in both current and voltage modes, providing flexibility. In addition, it can offer several advantages such as high slew rate, high speed, wider bandwidth and simpler implementation. Moreover in the CCCCTA one can control the parasitic resistance at X (R_X) port by input bias current. It is suited for realization of electronically tunable filters design.

In this paper a new electronically tunable current /voltage mode universal biquad filter using CCCCTAs is proposed which uses two CCCCTAs and two grounded capacitors. The filter circuit realizes LP, BP and HP responses simultaneously. The proposed circuit can also be operated in mixed mode with either voltage or current inputs and current or/and voltage outputs. It is clear from sensitivity analysis that biquad filter has very low sensitivities with respect to circuit active and passive components. Additionally the circuit enjoys an independent current control

DOI: 01.IJEPE.01.03.101

of parameters ω_o and ω_o/Q. Moreover, the LP and BP gain can be independently tuned by external biasing current of active elements without disturbing the centre frequency, quality factor and bandwidth. The performances of proposed circuit are illustrated by PSPICE simulations.

II. CCCCTA DESCRIPTION

The CCCCTA properties can be described in the following equation

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \\ I_O \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_X & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & -g_m & 0 \end{bmatrix} \begin{bmatrix} I_X \\ V_Y \\ V_Z \\ V_O \end{bmatrix} \qquad (1)$$

where R_x and g_m are the parasitic resistance at x terminal and transconductance of CCCCTA, respectively. R_x and g_m depend upon the biasing currents I_B and I_S of CCCCTA, respectively. The schematic symbol of CCCCTA is shown in Fig.1. The implementation of CCCCTA with CMOS transistors [23] is shown in Fig.2. For CMOS model of CCCCTA shown in Fig.2, R_x and g_m can be expressed as

$$R_X = \frac{1}{\sqrt{8\mu_n C_{OX} \frac{W}{L} I_B}} \qquad (2)$$

and

$$g_m = \sqrt{\mu_n C_{OX} \frac{W}{L} I_S} \qquad (3)$$

Where μ_n, C_{OX} and W/L are the electron mobility, gate oxide capacitance per unit area and transistor aspect ratio.

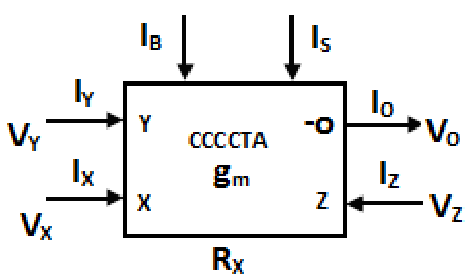

Figure 1. CCCCTA Symbol

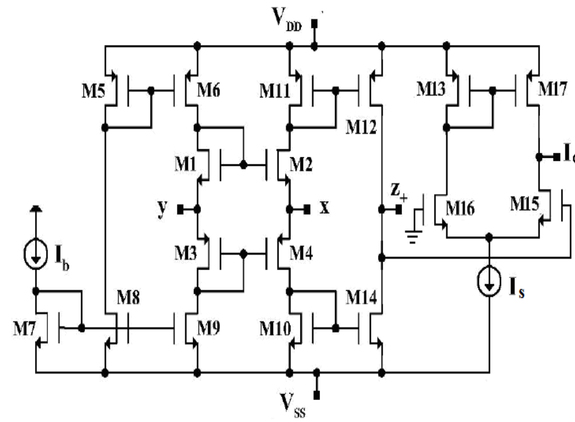

Figure 2. Implementation of CCCCTA using CMOS transistors

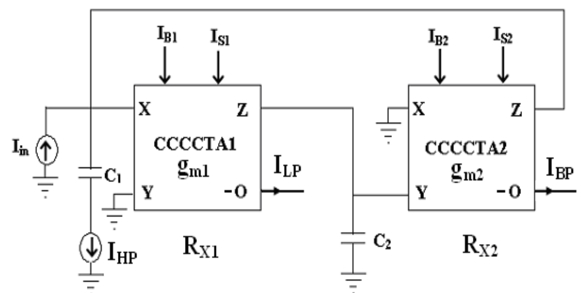

Figure 3. Proposed electronically tunable current-mode universal biquad filter

III. PROPOSED FILTER CIRCUIT

The proposed current mode universal filter is shown in Fig.3. It is based on two CCCCTAs and two grounded capacitors. Routine analysis yields the circuit transfer function $T_{LP}(s)$, $T_{BP}(s)$ and $T_{HP}(s)$ for the current outputs $I_{LP}(s)$, $I_{BP}(s)$ and $I_{HP}(s)$), given by

$$T_{LP}(s) = \frac{I_{LP}(s)}{I_{in}(s)} = \frac{g_{m1}R_{X2}}{s^2C_1C_2R_{X1}R_{X2} + sC_2R_{X2} + 1} \qquad (4)$$

$$T_{BP}(s) = \frac{I_{BP}(s)}{I_{in}(s)} = \frac{-g_{m2}sR_{X1}R_{X2}C_2}{s^2C_1C_2R_{X1}R_{X2} + sC_2R_{X2} + 1} \qquad (5)$$

$$T_{HP}(s) = \frac{I_{HP}(s)}{I_{in}(s)} = \frac{s^2C_1C_2R_{X1}R_{X2}}{s^2C_1C_2R_{X1}R_{X2} + sC_2R_{X2} + 1} \qquad (6)$$

The pole frequency (ω_o), the quality factor (Q) and Bandwidth (BW) ω_o/Q of each filter response can be expressed as

$$\omega_o = \left(\frac{1}{C_1C_2R_{X1}R_{X2}}\right)^{\frac{1}{2}} \qquad (7A)$$

DOI: 01.IJEPE.01.03.101

$$Q = \left(\frac{C_1 R_{X1}}{C_2 R_{X2}}\right)^{\frac{1}{2}} \quad (7B)$$

$$BW = \frac{\omega_O}{Q} = \frac{1}{C_1 R_{X1}} \quad (7C)$$

Substituting intrinsic resistances as depicted in (2) – (3), it yields

$$\omega_o = \left(\frac{1}{C_1 C_2} 8\mu_n C_{OX} \frac{W}{L}\right)^{\frac{1}{2}} \left(I_{B1} I_{B2}\right)^{\frac{1}{4}} \quad (8A)$$

$$Q = \left(\frac{C_1}{C_2}\right)^{\frac{1}{2}} \left(\frac{I_{B2}}{I_{B1}}\right)^{\frac{1}{4}} \quad (8B)$$

From (8), by maintaining the ratio I_{B1} and I_{B2} to be constant, it can be remarked that the pole frequency can be adjusted by I_{B1} and I_{B2} without affecting the quality factor. In addition, bandwidth (BW) of the system can be expressed by

$$BW = \frac{\omega_O}{Q} = \frac{1}{C_1}\left(8\mu_n C_{OX} \frac{W}{L} I_{B1}\right)^{\frac{1}{2}} \quad (9)$$

Equation (9) shows that the bandwidth can be controlled by I_{B1}. The gains of the LP, HP and BP can be expressed as

$$G_{LP} = g_{m1} R_{X2} = \sqrt{\frac{I_{S1}}{8I_{B2}}} \quad (10A)$$

$$G_{BP} = g_{m2} R_{X1} = \sqrt{\frac{I_{S2}}{8I_{B1}}} \quad (10B)$$

$$G_{HP} = 1 \quad (10C)$$

From. (10), it can be seen that, the LP and BP gain can be independently tuned by biasing current (I_{S1}) of CCCCTA1 and biasing current (I_{S2}) of CCCCTA2 respectively, without disturbing the pole frequency, quality factor and bandwidth. It can be seen that the filter circuit can realize the LP, BP and HP transfer function at current outputs of $I_{LP}(s)$, $I_{BP}(s)$ and $I_{HP}(s)$ simultaneously, respectively. The BR ($I_{BR}(s)$) and AP ($I_{AP}(s)$) can be obtained from the currents $I_{BR}(s) = I_{in}(s) + I_{BP}(s)$ and $I_{AP}(s) = I_{BR}(s) + I_{BP}(s)$, respectively, by keeping $g_{m2}R_{X1}$=1 and $g_{m1}R_{X2}$=1. All the output responses can be directly obtained by using multiple-output terminals of CCCCTAs.

An interesting aspect of proposed circuit is the mixed mode operation; the circuit is shown in Fig.4. The current- mode operation was discussed as above. The circuit can also be used as a current input, voltage outputs (as well as current outputs) just by measuring the responses at Z terminals of CCCCTA1 and CCCCTA2, which are LP and BP respectively. The three current outputs are simultaneously obtained as discussed earlier. Similarly, the circuit can be operated as voltage input current outputs (as well as voltage outputs) by applying voltage input at X terminal of CCCCTA2 and obtaining the responses at the three current outputs, where, LP, BP and HP functions are realized. The two voltage outputs namely BP and LP are simultaneously obtained. Thus, it is to be inferred that the proposed configuration can be used as (i) voltage input-voltage output (ii) voltage input-current output (iii) current input-current output (iv) current input-voltage output filters. At a time both current and voltage outputs are also obtained with either a current or a voltage input.

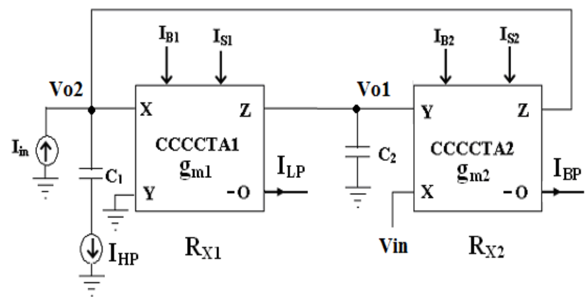

Figure 4. Mixed mode version of universal biquad filter

With V_{in}=0, three current outputs are as given in (4), (5) and (6). The two voltage outputs obtained are

$$\frac{V_{o1}(s)}{I_{in}(s)} = \frac{-R_{X1}}{s^2 C_1 C_2 R_{X1} R_{X2} + sC_2 R_{X2} + 1} \quad (11)$$

$$\frac{V_{o2}(s)}{I_{in}(s)} = \frac{sC_2 R_{X1} R_{X2}}{s^2 C_1 C_2 R_{X1} R_{X2} + sC_2 R_{X2} + 1} \quad (12)$$

Similarly, with I_{in}=0, the three current outputs are as:

$$\frac{I_{LP}(s)}{V_{in}(s)} = \frac{-g_{m1}}{s^2 C_1 C_2 R_{X1} R_{X2} + sC_2 R_{X2} + 1} \quad (13)$$

$$\frac{I_{BP}(s)}{V_{in}(s)} = \frac{sg_{m2} C_2 R_{X1}}{s^2 C_1 C_2 R_{X1} R_{X2} + sC_2 R_{X2} + 1} \quad (14)$$

$$\frac{I_{HP}(s)}{V_{in}(s)} = \frac{-s^2 C_1 C_2 R_{X1}}{s^2 C_1 C_2 R_{X1} R_{X2} + sC_2 R_{X2} + 1} \quad (15)$$

Two voltage outputs in this case:

$$\frac{V_{o1}(s)}{V_{in}(s)} = \frac{1}{s^2 C_1 C_2 R_{X1} R_{X2} + sC_2 R_{X2} + 1} \quad (16)$$

DOI: 01.IJEPE.01.03.101

$$\frac{V_{o2}(s)}{V_{in}(s)}=\frac{-sC_2R_{X1}}{s^2C_1C_2R_{X1}R_{X2}+sC_2R_{X2}+1} \quad (17)$$

Thus Equations (4), (5), (6) and (11) to (17) describe the mixed mode operation.

IV NONIDEAL ANALYSIS

For non-ideal case, the CCCCTA can be, respectively, characterized with the following equations

$$V_X=\beta V_Y+I_XR_X \quad (18)$$

$$I_Z=\alpha I_X \quad (19)$$

$$I_O=-\gamma g_m V_Z \quad (20)$$

Where β, α and γ are the transfer gains which deviate from 'unity' by the transfer errors. The non-ideal analysis of the proposed filter in Fig.3 yields the transfer functions as

$$T_{LP}(s)=\frac{I_{LP}(s)}{I_{in}(s)}=\frac{\gamma_1\alpha_1 g_{m1}R_{X2}}{s^2C_1C_2R_{X1}R_{X2}+sC_2R_{X2}+\beta_2\alpha_1\alpha_2} \quad \ldots(21)$$

$$T_{BP}(s)=\frac{I_{BP}(s)}{I_{in}(s)}=\frac{-\gamma_2 s g_{m2}R_{X1}R_{X2}C_2}{s^2C_1C_2R_{X1}R_{X2}+sC_2R_{X2}+\beta_2\alpha_1\alpha_2} \quad (22)$$

$$T_{HP}(s)=\frac{I_{HP}(s)}{I_{in}(s)}=\frac{s^2C_1C_2R_{X1}R_{X2}}{s^2C_1C_2R_{X1}R_{X2}+sC_2R_{X2}+\beta_2\alpha_1\alpha_2} \quad (23)$$

In this case, the ω_o and Q are changed to

$$\omega_o=\left(\frac{\beta_2\alpha_1\alpha_2}{C_1C_2R_{X1}R_{X2}}\right)^{\frac{1}{2}},\ Q=\left(\frac{\beta_2\alpha_1\alpha_2C_1R_{X1}}{C_2R_{X2}}\right)^{\frac{1}{2}} \quad (24)$$

The non ideal sensitivities of ω_o and Q with respect to active and passive components are described by (25) and (26) which are equal and less than half in magnitude.

$$S^{\omega_0}_{C_1,C_2,R_{X1},R_{X2}}=-\frac{1}{2},\ S^{\omega_0}_{\alpha_1,\alpha_2,\beta_2}=\frac{1}{2},\ S^{\omega_0}_{\gamma_1,\gamma_2,\beta_1}=0 \quad (25)$$

$$S^{Q}_{R_{X2},C_2}=-\frac{1}{2},\ S^{Q}_{R_{X1},C_1,\alpha_1,\alpha_2,\beta_2}=\frac{1}{2},\ S^{Q}_{\gamma_1,\gamma_2,\beta_1}=0 \quad (26)$$

Table 1 TSMC SPICE parameters for level 3, 0.35 µm CMOS process

	Parameters
NMOS	.MODEL MbreakN NMOS (LEVEL=3 TOX=7.9E-9 +NSUB=1E17 GAMMA=0.5827871 PHI=0.7 +VTO=0.5445549 DELTA=0 UO=436.256147 +ETA=0 THETA=0.1749684 KP=2.055786E-4 +VMAX=8.309444E4 KAPPA=0.2574081 +RSH=0.0559398 NFS=1E12 TPG=1 XJ=3E-7 +LD=3.162278E-11 WD=7.046724E-8 +CGDO=2.82E-10 CGSO=2.82E-10 CGBO=1E-10 +CJ=1E-3 PB=0.9758533 MJ=0.3448504 +CJSW=3.777852E-10 MJSW=0.3508721)
PMOS	.MODEL MbreakP PMOS (LEVEL=3 TOX=7.9E-9 +NSUB=1E17 GAMMA=0.4083894 PHI=0.7 +VTO=-0.7140674 DELTA=0 UO=212.2319801 +ETA=9.999762E-4 THETA=0.2020774 +KP=6.733755E-5 VMAX=1.181551E5 KAPPA=1.5 + RSH=30.0712458 NFS=1E12 TPG=-1 XJ=2E-7 +LD=5.000001E-13 WD=1.249872E-7 +CGDO=3.09E-10 CGSO=3.09E-10 + CGBO=1E-10 CJ=1.419508E-3 PB=0.8152753 +MJ=0.5 CJSW=4.813504E-10 MJSW=0.5)

V SIMULATION RESULT

To verify the theoretical analysis of the proposed filter circuit in Fig.3, PSPICE simulation has been used. In simulation, the CCCCTA is implemented using CMOS model as shown in Fig.2, with 0.35µm MOSFET from TSMC (the model parameters are given in Table 1). The dimensions of PMOS are determined as W=3µm and L=2µm. In NMOS transistors, the dimensions are W=3µm and L=4µm. Fig.5 Shows the simulated gain responses of the LP, HP and BP of the proposed circuit in Fig.2, designed with I_{B1}=6µA, I_{B2}=6µA, I_{S1}=50.5µA, I_{S2}=50.5µA and $C_1=C_2$=7pf. The supply voltages are V_{DD}= -V_{SS}=1.85V. The simulated pole frequency is obtained as 1.63 MHz. The power dissipations of the proposed circuit for the design values are found as 0.641 mW that is a low value. Fig.6 shows magnitude

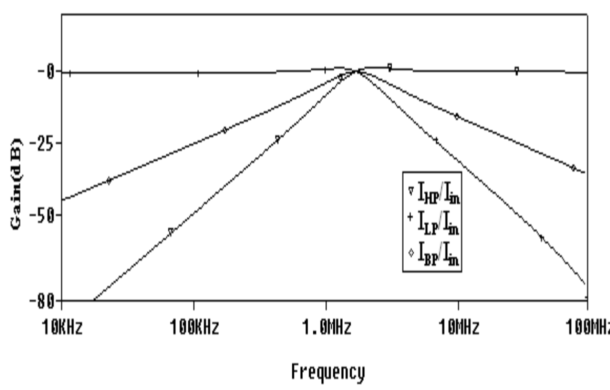

Figure 5. Simulated gain responses of circuit in Fig.3

DOI: 01.IJEPE.01.03.101

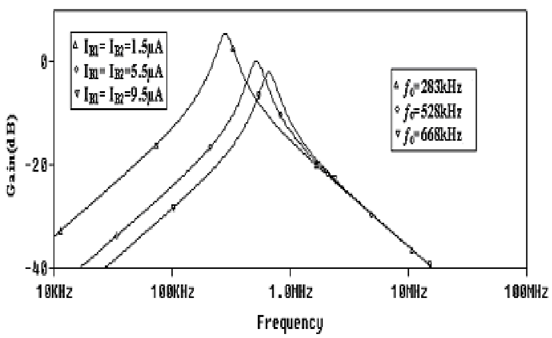

Figure 6. Band Pass responses for different value of $I_{B1}= I_{B2}$.

responses of BP function where I_{B1} and I_{B2} are equally set and changed for several values, by keeping its ratio to be constant for constant Q(=3.16). Other parameters are chosen as I_{S1}=50.5µA, I_{S2}=50.5µA, C_1=7pf and C_2= 7pf. The pole frequency (in Fig.6) is found to vary as 283KHz, 528KHz and 668KHz for three values of $I_{B1}=I_{B2}$ as 1.5µA, 5.5µA and 9.5µA, respectively which shows that pole frequency can be electronically adjusted without affecting the quality factor. Further simulations are carried out to verify the total harmonic distortion (THD). The circuit is verified by applying a sinusoidal current of varying frequency and constant amplitude of 10µA.The THD are measured at the I_{LP} output. The THD is found to be less than 3% while frequency is varied from 100 KHz to 450 KHz. The time domain response of LP output is shown in Fig.7. It is observed that 30µA peak to peak input current sinusoidal signal levels are possible without significant distortions.

VI CONCLUSION

An electronically tunable current/voltage bquad universal filter using only two CCCCTAs and two grounded capacitors is realized. The proposed filter offers the following advantages:

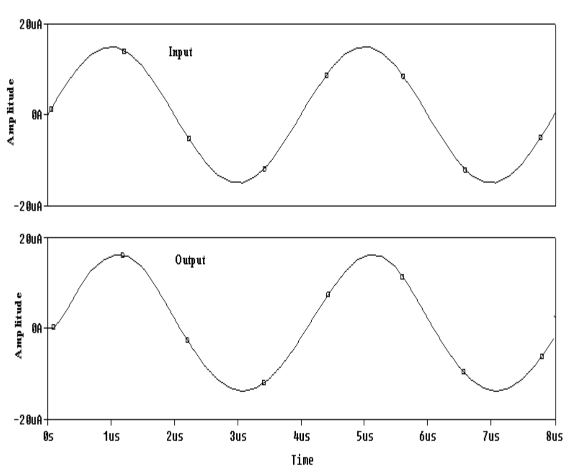

Figure 7. The time domain input and LP output waveforms

(i). Realizes LP' HP and BP responses in current form, simultaneously.

(ii). The proposed circuit can be operated in mixed mode as current or voltage input and voltage and/or current outputs, thus making the configuration versatile.

(iii). Both the capacitors are grounded.

(iv). Low sensitivity figures, low power consumptions and low THD.

(v). Filter parameters- ω_o, Q and ω_o/Q are electronically tunable with bias currents of CCCCTAs

(vi). Both ω_o and ω_o/Q, are orthogonally tunable.

(vii). LP and BP gain can be independently tuned by biasing currents of CCCCTA.

With above mentioned features it is very suitable to realize the proposed circuit in monolithic chip to use in battery powered, portable electronic equipments such as wireless communication system devices.

REFERENCES

[1]. G. W. Roberts and A. S. Sedra, "All current-mode frequency selective circuits," *Electronics Lett.,* vol .25, pp. 759-761, 1989.

[2]. B. Wilson, "Recent developments in current mode circuits," *IEE Proc. G*, vol. 137, pp. 63-77, 1990.

[3]. C. M. Chang, "Novel universal current- mode filter with single input and three outputs using only five current conveyors," *Electronics Lett.,* vol. 29, pp. 2005-2007, 1993.

[4]. C. M. Chang, "Universal active current-mode filter with single input and three outputs using CCIIs," *Electronics Lett.,* vol .29, pp. 1932-1933, 1993.

[5]. S. Özoğuz, A. Toker, and O. Çiçekoğlu, ''New current-mode universal filters using only four (CCII+)s,'' *Microelectronics J.*, vol. 30, pp. 255-258, 1999.

[6]. A. M. Soliman, "New current-mode filters using current conveyors," *Int'l J. Electronics and Communications* (*AEÜ*), vol. 51, pp. 275-278, 1997.

[7]. R. Senani, ''New current-mode biquad filter,'' *Int'l J. Electronics*, vol. 73, pp. 735-742, 1992.

[8]. Fabre, 0. Saaid, F. Wiest, and C. Boucheron, "High frequency application based on a new current controlled conveyor," *IEEE Tran. on Circuit and System.-I: Fundamental Theory and Applications*, vol. 43(2), pp. 82-91, 1996.

[9]. W. Kiranon, J. Kesorn, and N. Kamprasert, "Electronically tunable multi-function translinear-C filter and oscillators," *Electronics Lett*., vol. 33(7), pp. 573-574, 1997.

[10]. M. T. Abuelma'atti and N. A. Tassaduq, "New current-mode current controlled filters using current-controlled conveyor," *Int'l J. Electronics*, vol. 85, pp. 483-488, 1998.

[11]. I. A. Khan and M. H. Zaidi, "Multifunction translinear-C current mode filter," *Int'l J. Electronics*, vol. 87, pp. 1047-1051, 2000.

[12]. M. Sagbas and K. Fidaboylu, "Electronically tunable current-mode second order universal filter using minimum elements," *Electronics Lett*., vol. 40, pp. 2-4, 2004.

[13]. E. Yuce, S. Minaei, and O. Cicekoglu, "Universal current-mode active-C filter employing minimum number of passive elements," *Analog Integrated Circuits and Signal Processing,* vol. 46, pp. 169–171, 2006.

DOI: 01.IJEPE.01.03.101

[14]. T. Katoh , T. Tsukutani , Y. Sumi and Y. Fukui, "Electronically tunable current-mode universal filter employing CCCIIs and grounded capacitors," *ISPACS*, pp. 107-110, 2006.

[15]. S. Maheshwari and I. A. Khan, "High performance versatile translinear-C universal filter," *J. of Active and Passive Electronic Devices*, vol. 1, pp. 41-51, 2005.

[16]. R. Senani, V. K. Singh, A. K. Singh, and D. R. Bhaskar, "Novel electronically controllable current mode universal biquad filter," *IEICE electronics express*, vol. 1(14), pp. 410-415, 2004.

[17]. S. Minaei and S. Türköz, "Current-mode electronically tunable universal filter using only plus-type current controlled conveyors and grounded capacitors," *ETRI Journal*, vol. 26(4), pp .292-296, 2004.

[18]. T. Tsukutani, Y. Sumi, S. Iwanari and Y. Fukui, "Novel current-mode biquad using MO-CCCIIS and grounded capacitors," *Proceeding of 2005 International Symposium on Intelligent Signal Processing and Communication Systems*, pp. 433-436, 2005.

[19]. N. Pandey, S. K. Paul, A. Bhattacharyya and S. B. Jain, "A novel current controlled current mode universal filter: SITO Approach," *IEICE Electronics Express*, vol. 2(17), pp. 451-457, 2005.

[20]. C. Wang, H. Liu and Y. Zhao, "A new current-mode current controlled universal filter based on CCCII(±)," *Circuits System Signal Process*, vol.27, pp. 673-682, 2008.

[21]. S. Maheshwari and I. A. Khan, " Novel cascadable current-mode translinear-C universal filter," *Active Passive Electronics Components*, vol. 27(4), pp. 215-218, 2004.

[22]. M. Siripruchyanun and W. Jaikla, "Current controlled current conveyor transconductance amplifier (CCCCTA): A building block for analog signal processing," *Electrical Engineering,*" vol. 90, pp. 443-455, 2008.

[23]. M. Siripruchyanun, P. Silapan and W. Jaikla, "Realization of CMOS current controlled current conveyor transconductance amplifier and its applications," *J. of Active and Passive Electronic Devices*, vol. 4, pp. 35-53, 2009.

DOI: 01.IJEPE.01.03.101